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Impact of D-STATCOM placement on improving the reactive loading capability of unbalanced radial distribution system

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Abstract

In this paper, Distribution STATic COMpensator (D-STATCOM) are optimally placed in unbalanced radial distribution systems (UBRDS) using sensitivity approaches with an objective of improving the reactive loading capability of the network with maintaining voltage profile in an acceptable limit. Optimal locations of D-STATCOM are determined using Voltage Stability Index (VSI). Optimum size of D-STATCOM is obtained by variational algorithm subjected to minimization of total power loss. In order to quantitatively analyze the impact of D-STATCOM on voltage stability margin, Q-V curves are drawn using continuation power flow method. In this study the impact of D-STATCOM placement is investigated for large industrial load model with light, medium and high loading conditions. Also, load growth scenario is considered for better planning of the system. The results are obtained on standard 25-bus and IEEE-37 bus UBRDS to verify the practicability of proposed methodology.

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Keywords: D-STATCOM; Unbalanced Radial Distribution system; Optimum location; Optimum size; Voltage Stability Index

1. Main text

The demand of electrical power is continuously increasing in every sector like residential, commercial and industrial and since most of the loads are reactive in nature (motors, pumps, fans etc.) the demand of reactive power is continuously increasing. Also, demand of reactive power is more in case of unbalanced load [1]. Since, most of the

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power system loads are inductive in nature and demands lagging reactive power. So, reactive power compensation is required. It is economical to provide reactive power support nearer to the load in the distribution system. Reactive power is required to maintain the voltage to deliver the active power through the lines.

As the reactive loading of distribution system increases, voltage profile of the network decreases. Voltage collapse is the catastrophic result of a sequence of events leading to a low-voltage profile suddenly in a major part of the power system [2]. More reactive power demand increases feeder loss and reduces active power flow capability of the distribution system, whereas unbalancing also affects the operation of transformers and generators. Many authors have used Flexible AC Transmission Systems (FACTS) devices to improve the voltage stability of transmission network as given in [3]. The concise theory of reactive power control and voltage stability is well explained in [4]. Similarly, D-FACTS devices such as DVR, D-STATCOM and UPQC are used to maintain the voltage profile of the distribution network within acceptable limit by providing reactive power. Among all these compensating devices, D-STATCOM has several features, like low power losses, compact size and low cost [5]. Voltage stability is the ability of power system to maintain steady acceptable voltage at all buses in the system at normal operating conditions and after being subjected to a disturbance. A voltage stability indicator is proposed for analysis of voltage stability of distribution system in [6]. The mathematical equation of voltage stability analysis is derived in [7]. The methods for determining Q-V curve are explained in [8]. Q-V curve provides the reactive power margin and used for measurement of voltage stability [9]. Voltage stability of radial distribution systems can be enhanced by network reconfiguration as explained in [10]. D-STATCOM is used for voltage profile improvement of distributed wind generation as given in [11]. The benefits of D-STATCOM placement is to increase the reactive loading capability of distribution system in all loading conditions, voltage profiles at each bus of distribution system can be enhanced and kept in tolerable limits, system stability is improved to make best use of the distribution system, reactive power flow is reduced so as to decrease line losses.

From the literature survey, it is found that authors have proposed placement of D-STATCOM in balanced radial distribution system for voltage stability analysis. But, voltage stability analysis of UBRDS for finding critical loading condition with D-STATCOM placement is barely available in literature. In this paper, critical loading condition of UBRDS is determined with voltage dependent load models including load growth. Also, the impact of optimal placement of D-STATCOM in UBRDS is presented for enhancing the critical loading capability of UBRDS with voltage dependent load models including load growth. Continuation load flow method is applied to determine critical loading limits in the presence of D-STATCOM.

2. Load model

Load model will affect voltage instability, reactive power imbalance, power system planning, and availability of shunt devices. Common static load models for active and reactive power are expressed in a polynomial or an exponential form. The characteristic of the exponential load models can be given as:

$$P = P_o\left(\frac{V}{V_o}\right)^{n_p} \tag{1}$$

$$Q = Q_o\left(\frac{V}{V_o}\right)^{n_q} \tag{2}$$

where n_p and n_q stand for load exponents, P_o and Q_o stand for the values of the active and reactive powers at the nominal voltages. V and V_o stand for load bus voltage and load nominal voltage, respectively. The load exponents for different components are given in [12]. Also, the load growth equation is given as:

$$\mathrm{Load_i} = \mathrm{Load} \times (1 + \mathrm{r})^{\mathrm{m}} \tag{3}$$

where r =annual growth rate, m=plan period up to which feeder can take the load. In this paper, r=7% and m=5 years is taken for planning of distribution system. Load multiplication factors 0.5, 1.0 and 1.6 are taken as for light, medium and high loading conditions respectively.

3. Determination of optimal D-STATCOM location and size in UBRDS

Optimal locations of D-STATCOM are determined using Voltage Stability Index as in [13]. VSI is maximum in 17th branch i.e., 15th bus for 25-bus UBRDS and 1st branch i.e., 2nd bus for 37-bus UBRDS which is selected as optimal bus for D-STATCOM placement. The optimal size of D-STATCOM for each phase are determined by variational algorithm subjected to minimization of total power loss as in [14] and presented in Table 1 for 25-bus and IEEE-37 bus UBRDS respectively and it can be observed that as the load increases the reactive power demand increases and thereby to fulfill the increased reactive power demand the size of D-STATCOM increases. The per phase size of D-STATCOM is 150 kVAr for light load condition, 300 kVAr for medium load condition, 550 kVAr for high load condition and with consideration of 7 % load growth for 5 years it increased to 700 kVAr for 25 bus UBRDS. Similarly, the per phase size of D-STATCOM is 300 kVAr for light load condition, 550 kVAr for medium load condition, 900 kVAr for high load condition and with consideration of 7 % load growth for 5 years it increased to 1140 kVAr for 37 bus UBRDS.

Table 1: Optimal size of D-STATCOM

Loading Conditions	D-STATCOM Rating (kVAr) for 25 bus UBRDS			D-STATCOM Rating (kVAr) for 37 bus UBRDS		
	Ph-A	Ph-B	Ph-C	Ph-A	Ph-B	Ph-C
High	550	550	550	900	900	900
Medium	300	300	300	550	550	550
Light	150	150	150	300	300	300
With Load Growth	700	700	700	1140	1140	1140

4. Methodology

The basic equation of load flow analysis used for UBRDS are taken from [15] and the results are obtained with D-STATCOM placement in each phase of 25-bus [16] and IEEE-37 bus [17] UBRDS using MATLAB software version 7.8, 2009 [18]. The complete methodology used for finding the results is described by the flowchart given in Fig.1.

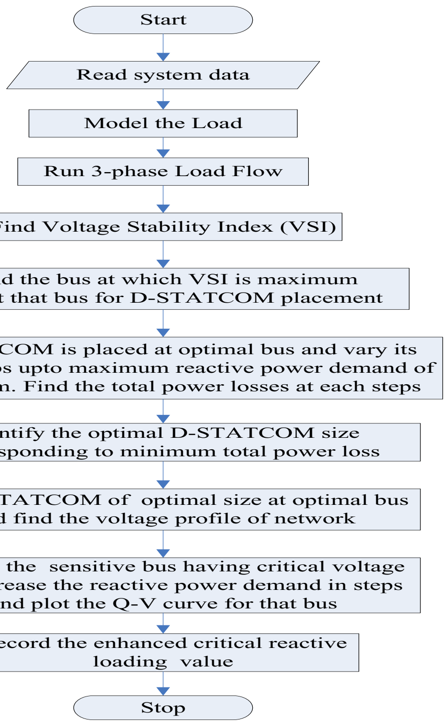

Fig.1. Flow chart of proposed methodology

In this study, the purpose of D-STATCOM placement is to improve the critical reactive loading capability of UBRDS by providing reactive power support. Q-V curves are drawn with installation of D-STATCOM to determine the critical loading values in each phase of UBRDS. In this study, critical voltage is taken as 0.9 p.u and increment in the reactive power demand is considered at the sensitive node only. It can be observed from the Q-V curves that the voltage stability limit is increased with optimal installation of D-STATCOM. This is due to; a part of the total power demand is locally provided by D-STATCOM. Considerable amount of feeder capacity is released for each phase after D-STATCOM placement.

5. Results and Discussion

5.1. Results for 25-bus UBRDS

Q-V curves for each phase with light loading condition are shown in Fig.2 and it can be seen that the critical reactive loading capability with base case for phase A is 900 kVAr, for phase B is 990 kVAr, for phase C is 1020 kVAr and after D-STATCOM placement it improves and reaches 1050 kVAr in phase A, 1140 kVAr in phase B, 1170 kVAr in phase C. Also, Q-V curves for each phase with medium loading condition are shown in Fig.3 and it can be seen that the critical reactive loading capability with base case for phase A is 510 kVAr, for phase B is 570 kVAr, for phase C is 650 kVAr and after D-STATCOM placement in each phase it improves and reaches 810 kVAr in phase A, 870 kVAr in phase B, 950 kVAr in phase C. Similarly, Q-V curves for each phase with high loading condition and with load growth are obtained and the improvement of critical reactive loading capability is recorded for each phase and presented in Table 2.

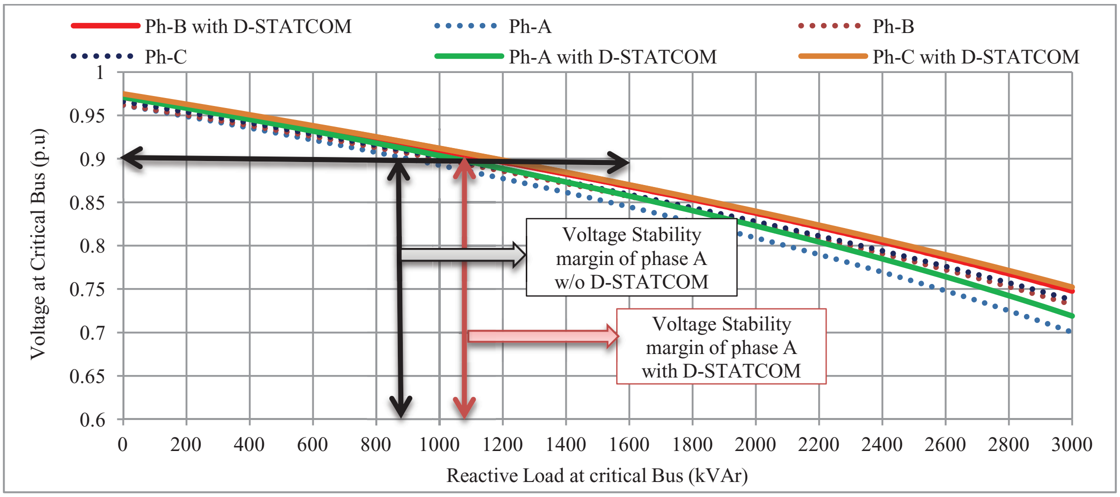

Fig.2. Q-V curves for large industrial motors at light load for 25-bus UBRDS

5.2. Results for IEEE 37-bus UBRDS

Q-V curves for each phase with light loading condition are shown in Fig.4 and it can be seen that the critical reactive loading capability with base case for phase A is 5400 kVAr, for phase B is 5400 kVAr, for phase C is 46500 kVAr and after D-STATCOM placement it improves and reaches 5630 kVAr in phase A, 5630 kVAr in phase B, 4800 kVAr in phase C. Also, Q-V curves for each phase with medium loading condition are shown in Fig.5 and it can be seen that the critical reactive loading capability with base case for phase A is 4820 kVAr, for phase B is 5010 kVAr, for phase C is 4220 kVAr and after D-STATCOM placement in each phase it improves and reaches 5180 kVAr in phase A, 5300 kVAr in phase B, 4470 kVAr in phase C. The improvement of critical reactive loading capability with all loading condition is recorded and presented in Table 3.

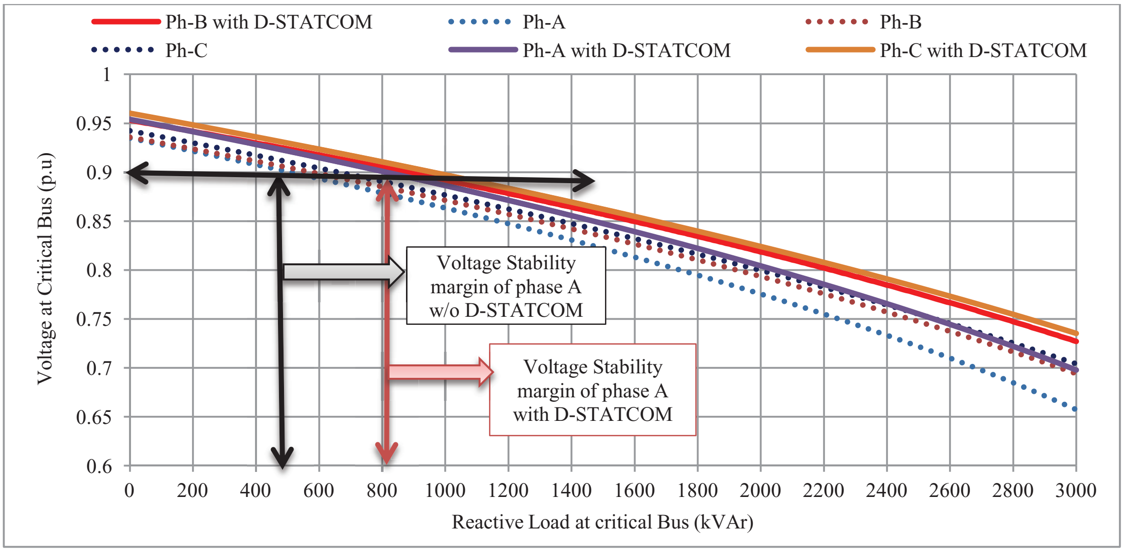

Fig.3. Q-V curves for large industrial motors at medium load for 25-bus UBRDS

Table 2: Critical Reactive Loading Values in kVAr for 25-bus mesh UBRDS

		Base case		
	Light Load	Medium Load	High Load	Load Growth
Ph-A	900	510	570	220
Ph-B	990	570	660	280
Ph-C	1020	650	810	470
		With D-STATCOM		
Ph-A	1050	810	1120	910
Ph-B	1140	870	1210	970
Ph-C	1170	950	1360	1170

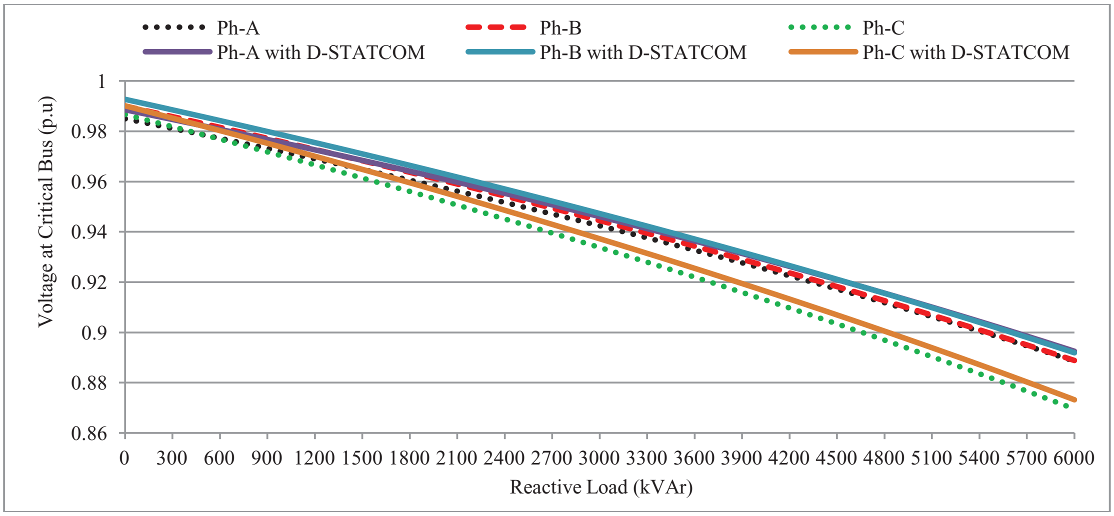

Fig.4. Q-V curve for large industrial motors at light load for 37-bus UBRDS

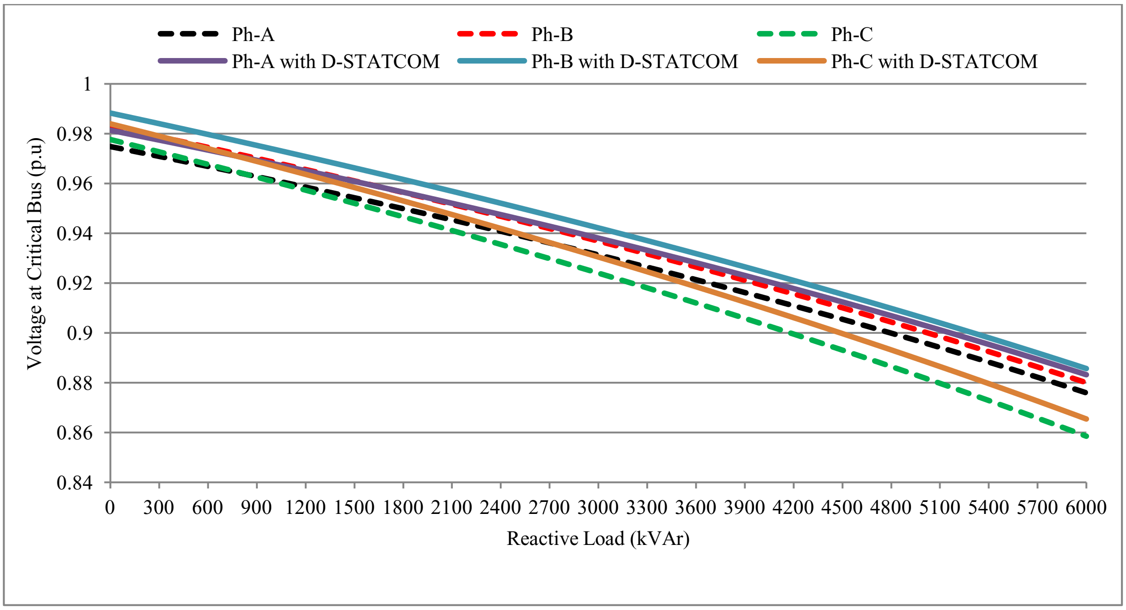

Fig.5. Q-V curve for large industrial motors at medium load for 37-bus UBRDS

From the Q-V curves for each phase shown in Fig.6 with high loading condition and it can be seen that the critical reactive loading capability with base case for phase A is 3760 kVAr, for phase B is 4300 kVAr, for phase C is 3300 kVAr and after D-STATCOM placement in each phase it improves and reaches 4400 kVAr in phase A, 4800 kVAr in phase B, 3930 kVAr in phase C. Similarly, Q-V curves for each phase with load growth are obtained and shown in Fig.7 and and it can be seen that the critical reactive loading capability with base case for phase A is 3060 kVAr, for phase B is 3880 kVAr, for phase C is 2860 kVAr and after D-STATCOM placement in each phase it improves and reaches 4010 kVAr in phase A, 4570 kVAr in phase B, 3600 kVAr in phase C.

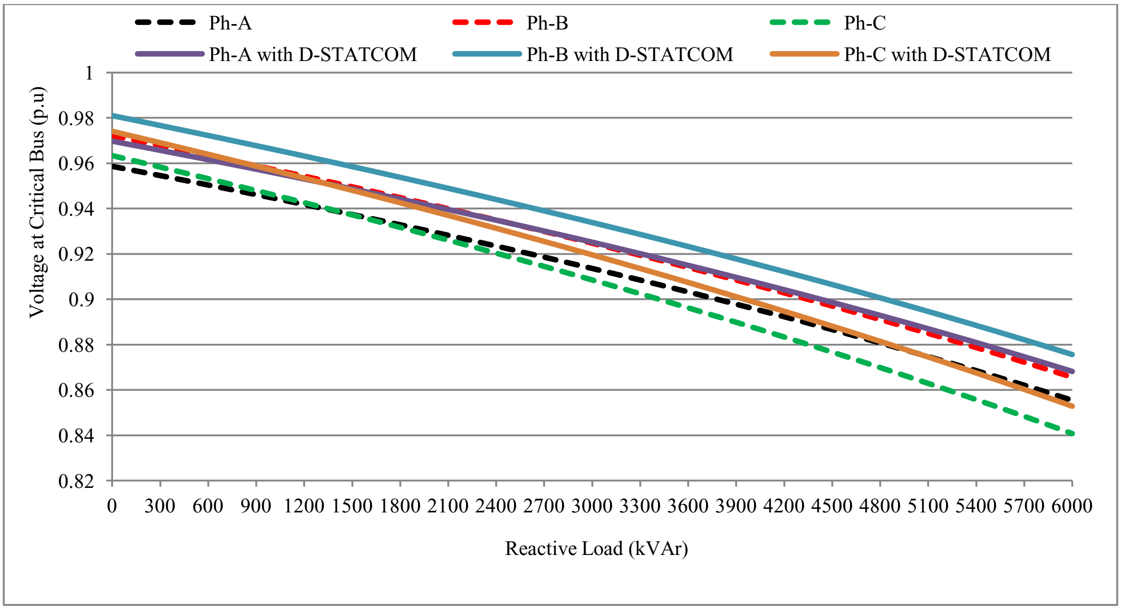

Fig.6. Q-V curve for large industrial motors at high load for 37-bus UBRDS

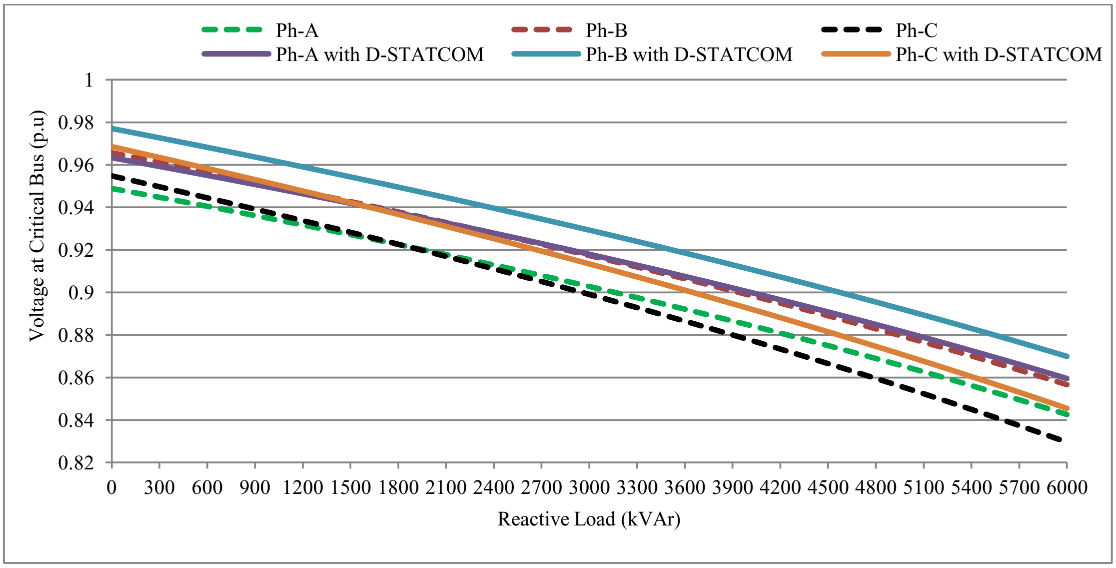

Fig.7. Q-V curve for large industrial motors with load growth for 37-bus UBRDS

Table 3: Critical Reactive Loading Values in kVAr for 37-bus mesh UBRDS

		Base case		
	Light Load	Medium Load	High Load	Load Growth
Ph-A	5400	4820	3760	3060
Ph-B	5400	5010	4300	3880
Ph-C	4650	4220	3300	2860
		With D-STATCOM		
Ph-A	5630	5180	4400	4010
Ph-B	5630	5300	4800	4570
Ph-C	4800	4470	3930	3600

Result shows the reactive loading capability of each phase gets improved after placement of D-STATCOM with all loading conditions including load growth for both test system.

6. Conclusions

This paper proposed an effective approach for improving the critical reactive loading capability of each phase for unbalanced radial distribution systems with placement of D-STATCOM. It is observed that the reactive loading capability of each phase is enhanced with D-STATCOM placement for all loading conditions. Power losses increases with load growth as the load demand increases. Accordingly, the rating of required D-STATCOM also increases to provide required reactive power demand. This proposed technique will help the distribution network operator to plan the distribution system with D-STATCOM.

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